ESC-5467-99-02

KEITHLEY

Model 2400 Service Manual Addendum

Introduction

This addendum is being provided in order to supply you with the latest information in the least possible time. Please incorporate this information into the manual before using the instrument.

2400-902-02 Rev. B / 9-96

Compliance considerations

Compliance limits

When sourcing voltage, you can set the SourceMeter to limit current from 1nA to 1.05A. Conversely, when sourcing current, you can set the SourceMeter to limit voltage from 200µV to 210V. The SourceMeter output will not exceed the programmed compliance limit.

Types of compliance

There are two types of compliance that can occur: "real" and "range." Depending upon which value is lower, the output will clamp at either the displayed compliance setting ("real") or at the maximum measurement range reading ("range").

The "real" compliance condition can occur when the compliance setting is less than the highest possible reading of the measurement range. When in compliance, the source output clamps at the displayed compliance value. For example, if the compliance voltage is set to 1V and the measurement range is 2V, the output voltage will clamp (limit) at 1V.

"Range" compliance can occur when the compliance setting is higher than the possible reading of the selected measurement range. When in compliance, the source output clamps at the maximum measurement range reading (not the compliance value). For example, if the compliance voltage is set to 1V and the measurement range is 200mV, the output voltage will clamp (limit) at 210mV.

Maximum compliance values

The maximum compliance values for the measurement ranges are summarized as follows:

Measurement range	Maximum compliance value
200mV	210 mV
2V	2.1V
20V	21V
200V	210V
1µA	1.05µA
10µA	10.5µA
100µA	105µA
1mA	1.05mA
10mA	10.5mA
100mA	105mA
1A	1.05A

When the SourceMeter goes into compliance, the "Cmpl" label or the units label (i.e., "mA") for the compliance display will flash.

Determining compliance limit

The relationships to determine which compliance is in effect are summarized as follows. They assume the measurement function is the same as the compliance function.

- Compliance Setting < Measurement Range = Real Compliance
- Measurement Range < Compliance Setting = Range Compliance

You can determine the compliance that is in effect by comparing the displayed compliance setting to the present measurement range. If the compliance setting is lower than the maximum possible reading on the present measurement range, the compliance setting is the compliance limit. If the compliance setting is higher than the measurement range, the maximum reading on that measurement range is the compliance limit

Taking the SourceMeter out of compliance

Verification measurements should not be made when the SourceMeter is in compliance. For purposes of the verification tests, the SourceMeter can be taken out of compliance by going into the edit mode and increasing the compliance limit.

NOTE *Do not take the unit out of compliance by decreasing the source value or changing the range. Always use the recommended range and source settings when performing the verification tests.*

Output voltage accuracy

Follow the steps below to verify that Model 2400 output voltage accuracy is within specified limits. This test involves setting the output voltage to each full-range value and measuring the voltages with a precision digital multimeter.

1. With the power off, connect the digital multimeter to the Model 2400 INPUT/OUTPUT jacks as shown in Figure 1-1.
2. Select the multimeter DC volts measuring function.

NOTE *The default voltage source protection value is 40V. Before testing the 200V range, set the voltage source protection value to >200V. To do so, press CONFIG then SOURCE V to access the CONFIGURE V-SOURCE menu, then select PROTECTION and set the limit value to >200V.*

3. Press the Model 2400 SOURCE V key to source voltage, and make sure the source output is turned on.
4. Verify output voltage accuracy for each of the voltages listed in Table 1-2. For each test point:
   - Select the correct source range.
   - Set the Model 2400 output voltage to the indicated value.
   - Verify that the multimeter reading is within the limits given in the table.
5. Repeat the procedure for negative output voltages with the same magnitudes as those listed in Table 1-2.
6. Repeat the entire procedure using the rear panel INPUT/OUTPUT jacks. Be sure to select the rear panel jacks with the front panel TERMINALS key.

Table 1-2
Output voltage accuracy limits

Model 2400 source range	Model 2400 output voltage setting	Output voltage limits (1 year, 18°C–28°C)
200mV	200.000mV	199.360 to 200.640mV
2V	2.00000V	1.99900 to 2.00100V
20V	20.0000V	19.9936 to 20.0064V
200V	200.000V	199.936 to 200.064V

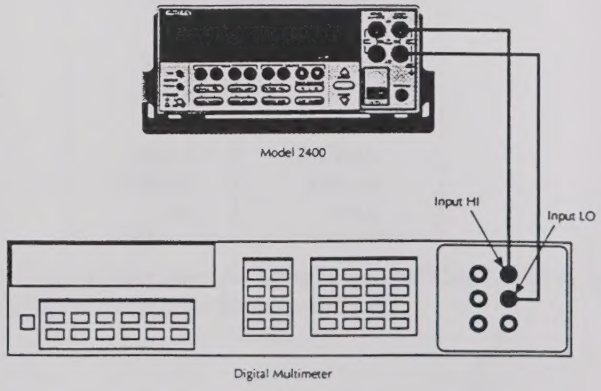


Figure 1-1
Voltage verification front panel connections

Voltage measurement accuracy

Follow the steps below to verify that Model 2400 voltage measurement accuracy is within specified limits. The test involves setting the source voltage to 95% of full-range values, as measured by a precision digital multimeter, and then verifying that the Model 2400 voltage readings are within required limits.

1. With the power off, connect the digital multimeter to the Model 2400 INPUT/OUTPUT jacks as shown in Figure 1-1.
2. Select the multimeter DC volts function.

NOTE *The default voltage source protection value is 40V. Before testing the 200V range, set the voltage source protection value to >200V. To do so, press CONFIG then SOURCE V to access the CONFIGURE V-SOURCE menu, and then select PROTECTION and set the limit value to >200V.*

3. Set the Model 2400 to both source and measure voltage by pressing the SOURCE V and MEAS V keys, and make sure the source output is turned on.
4. Verify output voltage accuracy for each of the voltages listed in Table 1-3. For each test point:
   - Select the correct source range.
   - Set the Model 2400 output voltage to the indicated value as measured by the digital multimeter.
   - Verify that the Model 2400 voltage reading is within the limits given in the table.

NOTE *It may not be possible to set the voltage source to the specified value. Use the closest possible setting, and modify reading limits accordingly.*

5. Repeat the procedure for negative source voltages with the same magnitudes as those listed in Table 1-3.
6. Repeat the entire procedure using the rear panel INPUT/OUTPUT jacks. Be sure to select the rear panel jacks with the front panel TERMINALS key.

Table 1-3
Voltage measurement accuracy limits

Model 2400 source and measure range*	Source voltage**	Model 2400 voltage reading limits (1 year, 18°C–28°C)
200mV	190.000mV	189.677 to 190.323mV
2V	1.90000V	1.89947 to 1.90053V
20V	19.0000V	18.9962 to 19.0038V
200V	190.000V	189.962 to 190.038V

*Measure range coupled to source range when simultaneously sourcing and measuring voltage.

** As measured by precision digital multimeter. Use closest possible value, and modify reading limits accordingly if necessary.

Output current accuracy

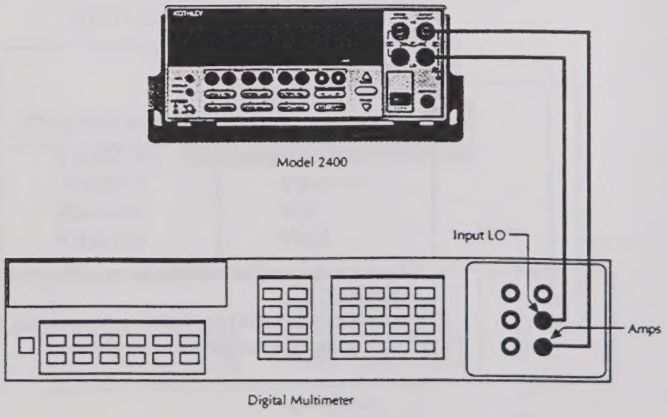
Follow the steps below to verify that Model 2400 output current accuracy is within specified limits. The test involves setting the output current to each full-range value and measuring the currents with a precision digital multimeter.

1. With the power off, connect the digital multimeter to the Model 2400 INPUT/OUTPUT jacks as shown in Figure 1-2.
2. Select the multimeter DC current measuring function.
3. Press the Model 2400 SOURCE I key to source current, and make sure the source output is turned on.
4. Verify output current accuracy for each of the currents listed in Table 1-4. For each test point:
   - Select the correct source range.
   - Set the Model 2400 output current to the correct value.
   - Verify that the multimeter reading is within the limits given in the table.
5. Repeat the procedure for negative output currents with the same magnitudes as those listed in Table 1-4.
6. Repeat the entire procedure using the rear panel INPUT/OUTPUT jacks. Be sure to select the rear panel jacks with the front panel TERMINALS key.

Table 1-4
Output current accuracy limits

Model 2400 source range	Model 2400 output current setting	Output current limits (1 year, 18°C–28°C)
1µA	1.00000µA	0.99905 to 1.00095µA
10µA	10.0000µA	9.9947 to 10.0053µA
100µA	100.000µA	99.949 to 100.051µA
1mA	1.00000mA	0.99946 to 1.00054mA
10mA	10.0000mA	9.9935 to 10.0065mA
100mA	100.000mA	99.914 to 100.086mA
1A	1.00000A	0.99640 to 1.00360A

Figure 1-2
Current verification connections



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Specifications

SOURCE SPECIFICATIONS[1]

Voltage Programming Accuracy (local or remote sense)

Range	Programming Resolution	Accuracy (1 Year) 23°C ±5°C ±% rdg. + volts	Noise (peak-peak) 0.1Hz – 10Hz
200.000 mV	5 µV	0.02% + 600 µV	5 µV
2.00000 V	50 µV	0.02% + 600 µV	50 µV
20.0000 V	500 µV	0.02% + 2.4 mV	500 µV
200.000 V	5 mV	0.02% + 24 mV	5 mV

TEMPERATURE COEFFICIENT (0°–18°C & 28°–50°C): ±(0.15 × accuracy specification)/°C.
MAX. OUTPUT POWER: 22W (four quadrant source or sink operation).
SOURCE/SINK LIMITS: ±21V @ ±1.05A, ±210V @ ±105mA.
VOLTAGE REGULATION: Line: 0.01% of range.
Load: 0.01% of range + 100µV.
NOISE 10Hz–1MHz (p-p): 10mV.
OVER VOLTAGE PROTECTION: User selectable values, 5% tolerance. Factory default = 40 volts.
CURRENT LIMIT: Bipolar current limit (compliance) set with single value. Min. 0.1% of range.
OVERSHOOT: <0.1% typical (full scale step, resistive load, 10mA range).

Current Programming Accuracy (local or remote sense)

Range	Programming Resolution	Accuracy (1 Year) 23°C ±5°C ±% rdg. + amps	Noise (peak-peak) 0.1Hz – 10Hz
1.00000 µA	50 pA	0.035% + 600 pA	5 pA
10.0000 µA	500 pA	0.033% + 2 nA	50 pA
100.000 µA	5 nA	0.031% + 20 nA	500 pA
1.00000 mA	50 nA	0.034% + 200 nA	5 nA
10.0000 mA	500 nA	0.045% + 2 µA	
100.000 mA	5 µA	0.066% + 20 µA	
1.00000 A[2]	50 µA	0.27 % + 900 µA	

TEMPERATURE COEFFICIENT (0°–18°C & 28°–50°C): ±(0.15 × accuracy specification)/°C.
MAX OUTPUT POWER: 22W (four quadrant source or sink operation).
SOURCE/SINK LIMITS: ±105mA @ 210V, ±1.05A @ 21V.
CURRENT REGULATION: Line: 0.01% of range.
Load: 0.01% of range + 100pA.
VOLTAGE LIMIT: Bipolar voltage limit (compliance) set with single value. Min. 0.1% of range.
OVERSHOOT: <0.1% typical (1mA step, R_L = 10kΩ, 20V range).

[1] Specifications valid for continuous output currents below 105mA. For operating above 105mA continuous for >1 minute, derate accuracy 10%/35mA above 105mA.
[2] Full operation (1A) regardless of load to 30°C. Above 30°C ambient, derate 35mA/°C and prorate 35mA/Ω load. 4-wire mode. For current sinking, up to 10W (external power) at 23°C. Above 23°C, derate 1W/°C.
[3] For sink mode, 1µA to 100mA range, accuracy is ±(0.15% + offset*4). For 1A range, accuracy is ±(1.5% + offset*8).

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A-3

See orig.

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Resistance Measurement Accuracy (4 wire remote sense)

Source I Mode, Auto Ohms

Range		Max Resolution		Default Test Current		Normal Accuracy (23°C ± 5°C) 1 Year, ± (%rdg + ohms)			Enhanced Accuracy (23°C ± 5°C)[5] 1 Year, ± (%rdg + ohms)
<2.0000	Ω[4]	1	μΩ	—		Source I_{ACC}	+ Measure V_{ACC}		Measure I_{ACC} + Measure V_{ACC}
20.0000	Ω	100	μΩ	100	mA	0.098%	+ 0.003	Ω	0.073% + 0.001 Ω
200.000	Ω	1	mΩ	10	mA	0.077%	+ 0.03	Ω	0.053% + 0.01 Ω
2.00000	kΩ	10	mΩ	1	mA	0.066%	+ 0.3	Ω	0.045% + 0.1 Ω
20.0000	kΩ	100	mΩ	100	μA	0.063%	+ 3	Ω	0.043% + 1 Ω
200.000	kΩ	1	Ω	10	μA	0.065%	+ 30	Ω	0.046% + 10 Ω
2.00000	MΩ	10	Ω	1	μA	0.11%	+ 300	Ω	0.049% + 100 Ω
20.0000	MΩ	100	Ω	1	μA	0.11%	+ 1	kΩ	0.052% + 500 Ω
200.000	MΩ	1	kΩ	100	nA	0.655%	+ 10	kΩ	0.349% + 5000 Ω
>200.000[4]	MΩ[4]	1	MΩ	—		Source I_{ACC}	+ Measure V_{ACC}		Measure I_{ACC} + Measure V_{ACC}

TEMPERATURE COEFFICIENT (0°–18°C & 28°–50°C): ±(0.15 × accuracy specification)/°C.
SOURCE I MODE, MANUAL OHMS: Total uncertainty = I source accuracy + V measure accuracy (4-wire remote sense).
SOURCE V MODE: Total uncertainty = V source accuracy + I measure accuracy (4-wire remote sense).
6-WIRE OHMS MODE: Available using active ohms guard and guard sense. Max. Guard Output Current: 50 mA (except 1A range). Accuracy is load dependent. Refer to manual for calculation formula.
GUARD OUTPUT IMPEDANCE: 0.1Ω in ohms mode.

[1] Speed = Normal (1 PLC).
[2] Accuracies apply to 2- or 4-wire mode when properly zeroed.
[3] 4-wire mode.
[4] Manual ohms mode only.
[5] Source readback enabled, offset compensation ON.

SYSTEM SPEEDS

MEASUREMENT[1]
MAXIMUM RANGE CHANGE RATE: 75/second.
MAXIMUM MEASURE AUTORANGE TIME: 40ms (fixed source)[2].
SWEEP OPERATION[3] READING RATES (rdg/second) FOR 60Hz (50Hz):

Speed	NPLC/Trigger Origin	Measure To Mem.	Measure To GPIB	Source-Measure To Mem.	Source-Measure To GPIB
Fast	0.01 / internal	2125 (2010)	1000 (1000)	1675 (1590)	900 (900)
	0.01 / external	1275 (1220)	910 (920)	1085 (1045)	830 (835)
Medium	0.10 / internal	510 (435)	510 (435)	475 (410)	475 (410)
	0.10 / external	440 (380)	440 (380)	415 (365)	415 (365)
Normal	1.00 / internal	59 (49)	59 (49)	58 (48)	58 (48)
	1.00 / external	57 (48)	57 (48)	57 (47)	57 (47)

Speed	NPLC/Trigger Origin	Source-Measure Pass/Fail Test[4] To Mem.	Source-Measure Pass/Fail Test[4] To GPIB	Source-Memory[4] To Mem.	Source-Memory[4] To GPIB
Fast	0.01 / internal	1000 (990)	760 (760)	200 (185)	200 (185)
	0.01 / external	940 (910)	710 (710)	195 (180)	195 (180)
Medium	0.10 / internal	400 (355)	400 (355)	155 (140)	155 (140)
	0.10 / external	390 (345)	390 (345)	150 (135)	150 (135)
Normal	1.00 / internal	57 (48)	57 (48)	46 (39)	46 (39)
	1.00 / external	56 (47)	56 (47)	46 (39)	46 (39)

ADDITIONAL SOURCE SPECIFICATIONS

TRANSIENT RESPONSE TIME: 30 µs minimum for the output to recover to its spec. following a step change in load.
COMMAND PROCESSING TIME: Maximum time required for the output to begin to change following the receipt of :SOURce:VOLTage|CURRent <nrf> command.
Autorange On: 10ms. **Autorange Off:** 7ms.
OUTPUT SETTLING Time: Maximum settle time required to reach 0.1% of final value after command is processed. 30µs minimum.
OUTPUT SLEW RATE: 0.5V/µs, 200V range, 100mA compliance. 0.08V/µs, 0.2V, 2V, and 20V ranges, 100mA compliance.
DC FLOATING VOLTAGE: Output can be floated up to ±250VDC from chassis ground.
REMOTE SENSE: Up to 1V drop per load lead.
COMPLIANCE ACCURACY: Add 0.1% of range to base specification.
OVER TEMPERATURE PROTECTION: Internally sensed temperature overload puts unit in standby mode.
RANGE CHANGE OVERSHOOT: Overshoot into a fully resistive 100kΩ load, 10Hz to 1MHz BW, adjacent ranges, Smooth Mode: (100mV) typical, except 20V/200V range boundary.
MINIMUM COMPLIANCE VALUE: 0.1% of range.

MEASURE SPECIFICATIONS [1, 2]

Voltage Measurement Accuracy (local or remote sense)

Range	Max. Resolution	Input Resistance	Accuracy (23°C ± 5°C) 1 Year, ± (%rdg + volts)
200.000 mV	1 µV	>10GΩ	0.012% + 300 µV
2.00000 V	10 µV	>10GΩ	0.012% + 300 µV
20.0000 V	100 µV	>10GΩ	0.015% + 1.5 mV
200.000 V	1 mV	>10GΩ	0.015% + 10 mV

TEMPERATURE COEFFICIENT (0°–18°C & 28°–50°C): ±(0.15 × accuracy specification)/°C.

Current Measurement Accuracy (local or remote sense)

Range	Max. Resolution	Voltage Burden[3]	Accuracy (23°C ± 5°C) 1 Year, ± (%rdg + amps)
1.00000 µA	10 pA	<1mV	0.029% + 300 pA
10.0000 µA	100 pA	<1mV	0.027% + 700 pA
100.000 µA	1 nA	<1mV	0.025% + 6 nA
1.00000 mA	10 nA	<1mV	0.027% + 60 nA
10.0000 mA	100 nA	<1mV	0.035% + 600 nA
100.000 mA	1 µA	<1mV	0.055% + 6 µA
1.00000 A	10 µA	<1mV	0.22 % + 570 µA

TEMPERATURE COEFFICIENT (0°–18°C & 28°–50°C): ±(0.1 × accuracy specification)/°C.

SINGLE READING OPERATION READING RATES (rdg/second) FOR 60Hz (50Hz):

Speed	NPLC/Trigger Origin	Measure To GPIB	Source-Measure[5] To GPIB	Source-Measure Pass/Fail Test[4, 5] To GPIB
Fast	0.01 / internal	200 (200)	65 (65)	65 (65)
Medium	0.10 / internal	160 (150)	60 (60)	60 (58)
Normal	1.00 / internal	46 (40)	31 (28)	30 (28)

COMPONENT HANDLER INTERFACE TIME: [4, 6]

Speed	NPLC/Trigger Origin	Measure Pass/Fail Test	Source Pass/Fail Test	Source-Measure Pass/Fail Test[7]
Fast	0.01 / external	0.96 ms (1.07 ms)	0.5 ms (0.5 ms)	4.0 ms (4.0 ms)
Medium	0.10 / external	2.5 ms (2.8 ms)	0.5 ms (0.5 ms)	5.5 ms (5.75 ms)
Normal	1.00 / external	17.5 ms (20.85 ms)	0.5 ms (0.5 ms)	20.5 ms (24 ms)

[1] Reading rates applicable for voltage or current measurements. Auto zero off, autorange off, filter off, display off, trigger delay = 0, source auto clear off, and binary reading format.

[2] Purely resistive load. 1μA and 10μA ranges <65ms.

[3] 1000 point sweep was characterized with the source on a fixed range.

[4] Pass/Fail test performed using one high limit and one low math limit.

[5] Includes time to re-program source to a new level before making measurement.

[6] Time from falling edge of START OF TEST signal to falling edge of END OF TEST signal.

[7] Command processing time of :SOURce:VOLTage|CURRent:TRIGgered <nrf> command not included.

GENERAL

NOISE REJECTION:

	NPLC	NMRR	CMRR
Fast	0.01	—	80 dB
Medium	0.1	—	80 dB
Normal	1	60 dB	120 dB[1]

LOAD IMPEDANCE: Stable into 20,000pF typical.
COMMON MODE VOLTAGE: 250VDC.
COMMON MODE ISOLATION: $>10^9\Omega$, <1000pF.
OVERRANGE: 105% of range, source and measure.
MAX. VOLTAGE DROP BETWEEN INPUT/OUTPUT AND SENSE TERMINALS: 5 volts.
MAX. SENSE LEAD RESISTANCE: 1MΩ for rated accuracy.
SENSE INPUT IMPEDANCE: $>10^{10}\Omega$.
GUARD OFFSET VOLTAGE: 150µV, typical.
SOURCE OUTPUT MODES:
Fixed DC level
Memory List (mixed function)
Stair (linear and log)
SOURCE MEMORY LIST: 100 points max.
MEMORY BUFFER: 5,000 readings @ 5½ digits (two 2,500 point buffers). Includes selected measured value(s) and time stamp. Lithium battery backup (3 yr + battery life).
PROGRAMMABILITY: IEEE-488 (SCPI-1995.0), RS-232, 5 user-definable power-up states plus factory default and *RST.
DIGITAL INTERFACE:
Safety Interlock: Active low input.
Handler Interface: Start of test, end of test, 3 category bits. +5V @ 300mA supply.
Digital I/O: 1 trigger input, 4 TTL/Relay Drive outputs (33V @ 500mA sink, diode clamped).
POWER SUPPLY: 88V to 264V rms, 50–60Hz (automatically detected at power up).
WARRANTY: 1 year.
EMC: Complies with European Union Directive 89/336/EEC (CE marking requirements), FCC part 15 class B, CTSPR 11, IEC 801-2, IEC 801-3, IEC 801-4.
VIBRATION: MIL-T-28800E Type III, Class 5.
WARM-UP: 1 hour to rated accuracies.
DIMENSIONS: 89mm high × 213mm wide × 370mm deep (3½ in × 8⅜ in × 14⁹⁄₁₆ in). Bench Configuration (with handle & feet): 104mm high × 238mm wide × 370mm deep (4⅛ in × 9⅜ in × 14⁹⁄₁₆ in).
WEIGHT: 3.21kg (7.08 lbs).
ENVIRONMENT:
Operating: 0°–50°C, 70% R.H. up to 35°C. Derate 3% R.H./°C, 35°–50°C.
Storage: –25°C to 65°C.

[1] Except lowest 2 current ranges = 90dB.

Specifications are subject to change without notice.

MP MASTER
MA26124